



**HAL**  
open science

# Unsteady position control of lean premixed flames in a narrow channel

Amanda Pieyre, Nasser Darabiha, Franck Richecoeur

► **To cite this version:**

Amenda Pieyre, Nasser Darabiha, Franck Richecoeur. Unsteady position control of lean premixed flames in a narrow channel. 53rd Japanese Symposium on Combustion, Nov 2015, Tsukuba, Japan. hal-01229028

**HAL Id: hal-01229028**

**<https://hal.science/hal-01229028>**

Submitted on 24 Aug 2020

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

# Unsteady position control of lean premixed flames in a narrow channel

A. Pieyre\*, N. Darabiha, F. Richecoeur

Laboratoire EM2C, CNRS, CentraleSupélec, Université Paris-Saclay, Grande Voie des Vignes, 92295 Chatenay-Malabry cedex, France

## Abstract

The stabilization of a premixed methane/air flame in a narrow quartz tube strongly depends on the thermal environment, and particularly on heat transfers between the wall and the gas. Such a coupling induces unsteady behaviours that have only been observed at mesoscale. The aim of this study is then to simulate this coupling by solving simultaneously the one-dimensional equations driving fluid and solid properties with complex chemistry. To validate the numerical simulations, an experimental test case is built. A cylindrical quartz tube has been used with a 5mm inner diameter, chosen above the conventional quenching diameter of the premix. An original unsteady phenomenon is observed experimentally: from a steady reactive configuration, a heat source is activated on the tube's external wall upstream from the flame, lasting few seconds. It makes the flame front move towards upstream until it reaches the maximum wall temperature imposed. The simulations predict well this behaviour proving the ability of the numerical strategy to compute unsteady couplings with different time scales and give access to all the variables as functions of time and space. This highlights new way of controlling a flame position in a channel by a localized and temporary heat input.

*Keywords:* Mesoscale combustion; Premixed flame; Flame stabilization; Unsteady position control

## 1. Introduction

Taking advantage of the high energy density of hydrocarbon fuels, micro combustion has a great potential for small generating power devices. One dimensional stability analysis and computation with detailed chemistry [4] and with simple chemistry [2] were made to obtain an overview of the flame stability and to examine the structures of those flames in detail. In the present work we use both experimental measurements and detailed chemistry simulations to study the flame behavior in a tube.

## 2. Experimental approach

The experiment is a test case for numerical validation. The goal of this experiment is to study the stability of a premix flame inside a cylindrical quartz tube, with a 5mm inner diameter, chosen above the conventional quenching diameter of the premix, so that a flame can evolve inside the tube without external assistance. The mixture, composed of methane and air is injected in the quartz tube from one end of the tube and is ignited at the other end of the tube. The flame evolution is measured by digital photography (Camera Nikon 7000D – Lens 70-300mm). The wall temperature evolution is measured using a 20 micrometer diameter thermocouple.

An original unsteady phenomenon is observed experimentally. Fig.1 describes this phenomenon : from a steady reactive configuration of the flame in the tube ( $t_0$ ), a heat source is activated on the tube's external wall at the  $x_F$  coordinate ( $t_1$ ), upstream from the flame front and lasting few seconds. Through a transitory mode the flame front, moves towards the external heat source position ( $t_2$ ) until it reaches the maximum wall temperature imposed at  $x_F$ . The external heat source is then removed and the flame stays stable in  $x_F$  ( $t_F$ ). This phenomenon shows the flame's dependency on thermal exchanges between gas and walls.

Fig.2 shows the flame front speed during this unsteady phe-

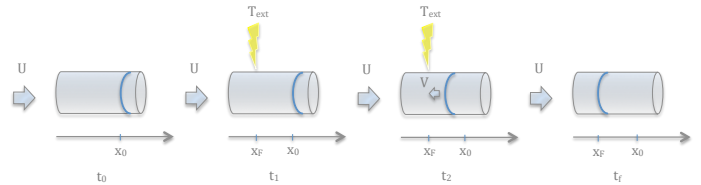


Figure 1: Detailed diagram of the unsteady phenomenon observed : the flame initially stabilized in the tube moves upstream when an external heat source is imposed.

nomon. It can be seen that the flame front speeds up to a maximum value and then stabilizes itself once the  $x_F$  coordinate has been reached, after about 6s. This delay time depends on the distance between the initial flame front position and the heat source.

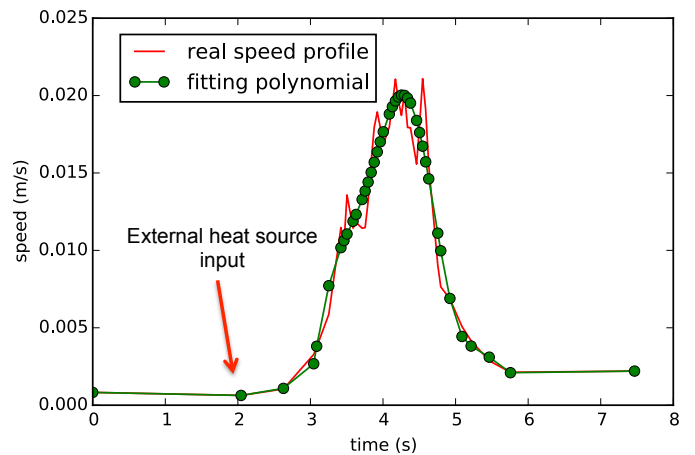


Figure 2: The flame front speed variation during the unsteady phenomenon. The flame speed increases to reach a peak and then decreases to reach the stabilization point.

### 3. Numerical approach : 1-D computations with detailed chemistry

To understand the flame dynamics with flame-wall structure coupling, a theoretical analysis was carried out. A fortran program for modeling the unsteady behaviour of the one-dimensional premixed flame called REGATH [1] with the GRI kinetic model was used. The numerical method used to solve the equations governing the flame propagation is a combination of a Newton's method and time integration.

The equations governing unsteady one-dimensional flame propagation [3] may be written for gas (1) and solid (2) energy and species mass function (3):

$$\rho u \frac{\partial H_G}{\partial x} = \frac{\partial}{\partial x} \left[ \lambda_G \frac{\partial T_G}{\partial x} \right] - \sum_{k=1}^K \rho Y_k V_k H_k - \frac{2\pi r_i}{\pi r_i^2} h_i (T_G - T_S) \quad (1)$$

$$\rho_S c_{ps} \frac{\partial T_S}{\partial t} = \frac{\partial}{\partial x} \left[ \lambda_S \frac{\partial T_S}{\partial x} \right] - \frac{2r_e}{r_e^2 - r_i^2} h_e (T_S - T_A) + \frac{2r_i}{r_e^2 - r_i^2} h_i (T_G - T_S) \quad (2)$$

$$\rho u \frac{\partial Y_k}{\partial x} = - \frac{\partial}{\partial x} [\rho Y_k V_k] + \dot{\omega}_k W_k \quad (3)$$

In these equations,  $x$  is the spatial coordinate,  $T$  the temperature,  $Y_k$  the mass fraction of the  $k^{th}$  species,  $u$  the velocity of the fluid premix,  $\rho$  the mass density,  $W_k$  the molecular weight of the  $k^{th}$  species,  $c_{P_k}$  the constant pressure heat capacity of the  $k^{th}$  species,  $\lambda$  the thermal conductivity,  $H_k$  the gas total enthalpy of the  $k^{th}$  species,  $V_k$  the diffusion velocity of the  $k^{th}$  species,  $r_i$  and  $r_e$  internal and external radius of the tube,  $h_i$  and  $h_e$  internal and external heat transfer coefficients.

The boundary conditions are :

$$x \rightarrow -\infty, T_{GAS} = T_{WALL} = T_0, Y_k = Y_{k0}, \dot{M} = \rho V.$$

$$x \rightarrow +\infty, \frac{dT_{GAS}}{dx} = \frac{dT_{wall}}{dx} = \frac{dY_k}{dx} = 0$$

The aim here is to reproduce the unsteady phenomenon observed experimentally, by imposing a temperature peak upstream from the flame front in REGATH. The results highlight the heat exchange between the wall and the unburnt gases by showing a growing temperature peak in the wall's temperature profile, and a flame front moving towards this peak. The external temperature profile imposed may be written as follows:

$$T_A = T_{ext0} + (T_{max} - T_{ext0}) \exp(\alpha(x - x_F)^2)$$

With  $T_{ext0} = T_{ext} = 298.0$  K,  $T_{max} = 2000$  K,  $\alpha = 40.0$  et  $x_F = 26$  cm.

Fig.3 shows the wall (e.g. black curve) and gas (e.g. red curve) temperature profile for several iterations progress. The wall and

gas temperature profiles, show two peaks, one principal peak located at the flame front, and a secondary peak, where the temperature increases as the iterations progress, and which represents the external heat source. The wall conveys the heat to the gas, which is then preheated and accelerated.

It can be seen clearly in Fig.3 that the flame front moves towards the wall's temperature secondary peak upstream. The flame front stabilizes itself at the  $x_F$  coordinate of the external temperature profile imposed after a large number of iterations.

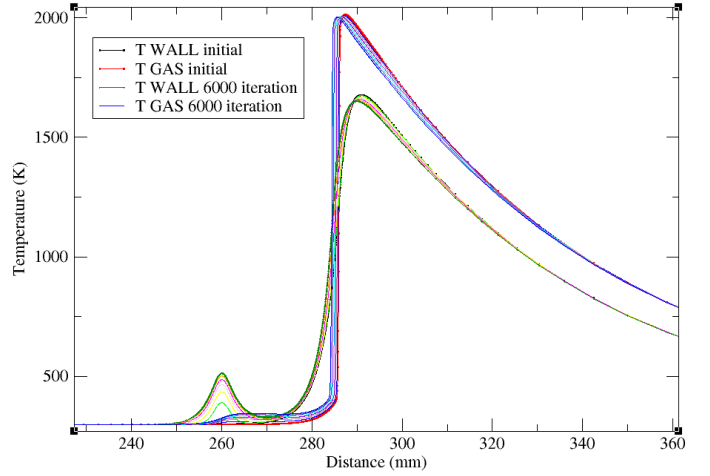


Figure 3: Temperature profile of the gas and wall at several iterations progress.

This global view on Fig.3 allows to assess the order of temperature's magnitude of the phenomenon.

### 4. Conclusion

An analytical solution is obtained for flame propagation. It is shown that the one dimensional computation with detailed chemistry, that takes in account the flame-wall coupling, reproduces well the unsteady phenomenon observed experimentally.

### References

- [1] S Candel, T Schmitt, and N Darabiha. Progress in transcritical combustion. *23rd ICDERS*, 2011.
- [2] Yiguang Ju and Bo Xu. Theoretical and experimental studies on mesoscale flame propagation and extinction. *Proceedings of the Combustion Institute*, 30(2):2445 – 2453, 2005.
- [3] Robert J Kee, Joseph F Grcar, Mitchell D Smooke, and James A Miller. A fortran program for modeling steady laminar one-dimensional premixed flames. 1985.
- [4] K. Maruta, J.K. Parc, K.C. Oh, T. Fujimori, S.S. Minaev, and R.V. Fursenko. Characteristics of microscale combustion in a narrow heated channel. *Combustion, Explosion and Shock Waves*, 40(5):516–523, 2004.